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The utilization of wind energy in the Brazilian electric sector's expansion

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Abstract

The Brazilian electric sector's supply crisis established in 2001 urges for short, medium and long term solutions. In this scenario, renewable energy sources, specially wind energy, gain distinction as a feasible alternative of seasonal stability in energy supply by means of complementation between natural wind regimes and hydro utilization, the basis of Brazilian's electric origin, as well as the utilization of the vast renewable natural resources potential existent in the country. An alternative renewable sources utilization program can include distinct technologies such as: biomass; solar energy; wind energy and small hydroelectric stations among others. Amongst the alternative technologies presented, the present article focuses on evaluating the opportunities of wind resources utilization, taking into consideration the Brazilian experience in wind utilization; the national potential; the legal boundary in formation and the barriers and opportunities presented to the development of this technology. The choice of wind energy is explained by its large worldwide growth at a competitive price and due to it being completely feasible in a large part of Brazil's territory from the perspective of the existence of a vast and reliable wind potential for immediate utilization.

Keywords: Wind energy; Brazilian wind potential; Legal boundary; Opportunities

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1. Introduction

Until the 1970s, the expansion of the Brazilian electric energy market was determined by income from scale economies obtainable by the development and use of technologies that guaranteed a growing raise in transmission and generation equipment capacity. This technological paradigm guarantees the maintenance of a technological accomplishment and its institutional stability, sustained by continuously overcoming technical difficulties and intrinsically related to the order of the necessary adjustment to the institutional and economic model adopted by National State's economies.

From the 1970s onwards, as a reflection of the new readings given to the electric sector as well as the financial and economic crisis experienced by the National States, limitations imposed by a new thinking that focuses the relations of activities of the energy sector and the environment were added. This way, the traditional expansion model of the electric sector loses breath, consequently allowing for the research and development of new technologies that contribute to a new institutional order and to breaking the current technological paradigm [1].

In this sense, the development of the named alternative (renewable) technologies is a direct reflex of the new institutional orientations and surpassing of the technological paradigm based on the growing raise of capacity installed by generating plants. Therefore, there is an encouragement towards promoting the debate around distributed generation, considering the utilization of energetic potentials from each region and their contributions to sustainable development.

From the list of renewable technologies, wind energy has been presenting a significant growth. An interest increase from concessionaries in investing in this technology has been registered, making the utilization of this source into a promising market. Each year, records of installed capacity are set, cost-effective turbines developed and technological innovations and improvements are reached consequently allowing for larger technical, environmental and economic gains.

Until the end of the year 2002, wind turbines with a total power of 32,047 MW were installed worldwide. From these, around 23,800 MW are generated in Europe. Currently, Northern Europe accounts for the largest market, led by Germany, Spain and Denmark. From the total 6160 MW of power installed in 2002, these three countries were responsible for 85.5%, which equals 5270 MW.

According to a prediction for the year 2007 [2], the worldwide installed wind power should increase from the current 32,047 MW (data from the end of 2002) to 58,632 MW until 2007. This means an average worldwide annual installation of 10,256 MW during the next 5 years.

In Brazil, the experience with the utilization of wind for generating electric energy still is little expressive. However, the confirmation of the existence of a large wind source distributed in a large portion of the national territory, specially on the Northern coast, allied with the emerging necessity of expansion in the electric supply system has pointed to a fast insertion of this source into the national energy basis.

2. The Brazilian wind potential

The utilization of wind resources as energy source requires an extensive evaluation of the wind potential existent in the location. For such, a quality and precise wind data collection is essential. In Brazil, as in various parts of the world, there is almost no wind data with the appropriate quality for an evaluation of wind potential. Companies and government institutions have, with time, changed their profile in relation to defined goals for the realization of wind data collection. In past dec-

ades, these companies did not collect wind data with the aim of utilizing these for generating electricity, but as information basis for use in agriculture and air and sea navigation among others.

In the past years, reflecting the interest of international investors on the utilization of the national wind potential, it is already noticeable that some energy concessionary companies and State departments are investing on wind data collection with the intent of utilizing it for electricity generation. The first anemometers with automatic data collection and special sensors for wind data measurements, with the purpose of electric energy generation, were only installed in the beginning of the 1990s in Ceará and Fernando de Noronha/PE. Various Brazilian States have recently started wind data collection programmers, such that today there are hundreds of automatic anemometers scattered over the national territory.

The recent availability of precise wind data, along with practically endless coastal winds, indicates a huge unexplored wind potential. The analysis of data from various North-eastern areas, especially on the coast, confirms the existence of winds appropriate for electric energy generation with high average speeds, little direction variation and small turbulence all year long. All this coupled with low gust wind values.

A lot of attention has been paid to the wind utilization in the Northeast region; especially in the States of Ceará and Rio Grande do Norte, as these have one of the largest potentials in the country. However, it was not only on the North-eastern coast that areas with a high wind potential were detected. In Minas Gerais for instance, a wind station has been in operation since 1994, in a location (over 1000 km away from the coast) with (excellent) good wind conditions. New locations that are being measured by the Minas Gerais Electric Company (Cemig, Companhia Energética de Minas Gerais) have excellent wind potential conditions.

Brazil is divided into five geographical regions; the North, Northeast, South, Southeast and Midlands and Midwest, with a national territory of 8,514,215 km^2 in between latitudes $5^\circ 16'$ N and 33° W and longitudes $32^\circ 23$ W and $73^\circ 2'$ E. The country has different climates, from equatorial (humid and semi-humid) in the North region to subtropical in the South region. In concerns to relief, "extensive plains with average altitudes below 250 m—among which the ones in the Amazon, Pantanal and Rio Grande do Sul stand out—oppose the plateaus with average altitudes between 750 and 1000 m that extend from the South up to the Midlands" [3].

In 2001, the Ministry of Mines and Energy, through the Electric Energy Research Centre (CEPEL, Centro de Pesquisas de Energia Elétrica), published the Brazilian Wind Potential Atlas (Atlas do Potencial Eólico Brasileiro) offering relative information to the behaviour of winds in all national territory. The Brazilian wind atlas reveals that Brazil has an estimated potential of 143.47 GW, for winds with an annual average speed equal to or higher than 7.0 m/s, making an estimated annual generation of 272,220 TWh/year available, with an area of 71,735 km^2 (0.8% of the national territory) needed for this. This estimate assumes an average land occupation density of 2 MW/km_2 and the turbine performance

curves at a height of 50 m. The atlas also shows the existence of a few privileged regions, among which the mountainous regions, the coast line in the Northeast region, specific places in the South region and reasonable average speeds in a variety of spots in the country.

In the North region, the Amazon does not show itself as a recommended place for wind energy extraction, as its wind records are in the 3.0–4 m/s range, at a height of 50 m. However, when evaluating higher regions, as is the case in the State of Roraima, a very reasonable potential is found. In the coastline of the Amazon, especially in the States of Pará and Maranhão and also in Amapá, the indicated speeds are quite high. Along with a high average annual value, the winds in the North region also have small seasonal variation, which also consists of a major advantage for energy generation. Another advantage is the relatively low gust winds.

The Northeast region in Brazil has a fantastic wind potential through its entire coastline, which can be broadly enlarged if a future offshore utilization is considered. String winds are also present in higher regions. While the regions far from the coast, the North-eastern countryside, sometimes also show average annual values almost as high as on the coast, specially in places higher up (with average values around 5 and 5.5 m/s.) Three states in the Northeast; Ceará, Bahia and Rio Grande do Norte have already consolidated their wind atlases.

The State of Ceará, with an area of 147,348 km_2, presents an installable wind energy potential of 5.8 GW according to its wind atlas published in 2001, allowing for an annual production of 12 TWh/year for winds beginning at 7 m/s at a height of 50 m and a capacity factor of 24%. The total area potentially useful for this utilization is 2911 km^2 (less than 2% of its territory). For utilizations at a height of 70 m, the technically utilized potential goes up to 24 GW, allowing for an annual generation of 51.9 TWh/year for winds beginning at 7 m/s and a capacity factor of 24%, with a necessary potentially useful total area of 12,426 km^2, the equivalent to 8.5% of its territory [4].

The State of Bahia meanwhile occupies an area of 567,295.03 km^2 and has a technically utilizable potential of 5.6 GW. According to the wind atlas published in 2002, this enables an annual generation of 12.32 TWh/year, for utilization of winds beginning at 7 m/s at a height of 50 m and a capacity factor of 25%, with a necessary potentially useful total area of 2373 km^2 (0.45% of its territory). For utilizations at a height of 70 m, the potential reaches 14.46 GW, with a generated energy of 31.90 TWh/year and an occupied area of 6.067 km^2, which represents 1% of the territory [5].

In the Midwest region, the map confirms the existence of reasonable winds at around 6.5–7.5 m/s in areas near the Paraguayan border. In the Southeast region, there are good winds in the Norte Fluminense, in Espírito Santo, in the higher regions of the Minas Gerais and São Paulo States, as well as throughout the coastline along with a future offshore utilization.

In the South region, the State of Rio Grande do Sul, with an area of 282,062 km^2, shows a very high future utilization potential. This State's wind

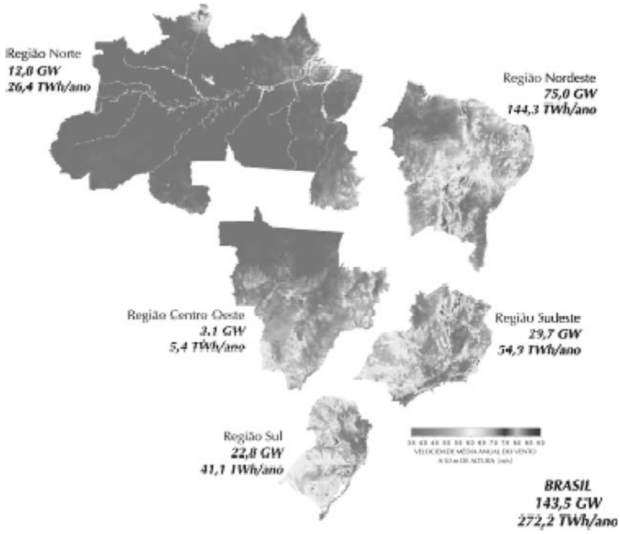

Fig. 1. Estimated wind potential for average annual winds equal to or higher than 7.0 m/s [3].

atlas, published in 2002, indicates an estimated onshore potential of 15.8 GW, for areas with winds equal to or higher than 7.0 m/s, at a height of 50 m and a capacity factor of 29%, allowing for the generation of 41.69 TWh/year, for a useful area of 10,558 km^2 (3.7% of the territory). For utilizations at a height of 75 m, the atlas indicates a potential that reaches 54.43 GW and 31.90 TWh/year of energy produced in an area of 36,284 km^2, which would occupy 12.9% of its territory [6]. Fig. 1 shows the distribution of the national wind potential per region.

3. The Brazilian experience with the use of wind energy

The setup of a 75 kW turbine on the Fernando de Noronha island marked the beginning of the utilization of wind resources for the generation of electric energy in Brazil. Today the country has an installed capacity of 21,240 kW with medium sized wind turbines connected directly to the electric network. Furthermore, there are hundreds of windmills (multi-pás turbines) for water pumping and dozens of small sized wind turbines operating in isolated places of the conventional network for battery charging, telecommunication systems and rural electrification.

Currently in Brazil, institutes and Research Centres have been dedicated to the study, development and application and diffusion of this technology, as well as the quantification and qualification of the possible utilization areas. Among this group of institutions is worth highlighting the Sérgio Brito Wind and Solar Energy Reference Centre (CRESESB, Centro de Referência para Energia Solar e Eólica Sérgio

Brito) connected to the Electric Energy Research Centre (CEPEL, Centro de Pesquisas de Energia Elétrica) and the Brazilian Wind Energy Centre (CBEE, Centro Brasileiro de Energia Eólica) which is connected to the Federal University of Pernambuco (Universidade Federal de Pernambuco) [7].

The presence of wind energy in electric energy generation is insignificant, accounting for 21,240 kW of installed power, distributed in only eight wind stations operating in the country.

3.1. Fernando de Noronha Plant—State of Pernambuco

The plant on the archipelago of Fernando de Noronha was set up in 1992, it has a turbine composed of a 75 kW asynchronous generator, a rotor with a diameter of 17 m and a 23-m high Danish Folkecenter tower. The enterprise is the result of a partnership between the Federal University of Pernambuco Wind Energy Group (UFPE, Grupo de Energia Eólica da Universidade Federal de Pernambuco) with financing from Folkecenter and the Pernambuco Energy Company (CELPE, Companhia Energética de Pernambuco). The unit has an average annual generation of 120 MWh/year.

A second turbine operating with a 225 kW generator, 13-m long blades and a 30-m high tower was set up in 2001. This second unit was implemented by the Brazilian Wind Energy Centre (CBEE, Centro Brasileiro de Energia Eólica) with the support of the RISO National Laboratory of Denmark and financing from the National Agency of Electric Energy (ANEEL, Agência Nacional de Energia Elétrica).

3.2. Morro do Camelinho Experimental Wind Station—State of Minas Gerais

Set up in 1994 at Gouveia City, this station is composed by 4250 kW turbines, with 29-m diameter rotors and a 30-m high tower, with an installed capacity of 1 MW. The project was conceived and carried out by the Minas Gerais Energy Company (CEMIG, Companhia Energética de Minas Gerais), with financial support from the German Government. The equipments were supplied by the Take company. The station's average electricity generation is estimated at 2000 MWh/year.

3.3. Taíba Wind Station—State of Ceará

In 1999, this station, along with the one in Prainha was the first commercial wind park set up in Brazil. The Taíba park, set up in an area of dunes in São Gonç alo do Amarante City, has an installed capacity of 5 MW, composed by 10 Wobben–Enercon 500 kW turbines, synchronous generators, 40-m diameter rotors and a 45-m high tower. The average annual generation is estimated at around 17,500 MWh.

3.4. Prainha Wind Station—State of Ceará

The Prainha station, situated in Aquiraz City, currently is the wind park with the largest installed capacity in South America, with 10 MW installed through 20 Wobben–Enercon 500 kW turbines. The turbines use synchronous generators, 40-m diameter rotors and a 45-m high tower. The project was carried out by Wobben–Enercon and started its commercial operation in 1999. The average annual generation is estimated at around 35,000 MWh.

3.5. Palmas Wind Station—State of Paraná

This was the first wind park set up in the South of the country and it started up in 1999. The station is located at Palmas City, with an installed power of 2.5 MW, using five Wobben–Enercon 500 kW turbines. The turbines use synchronous generators, 40-m diameter rotors and a 45-m high tower. The project was carried out by the Paraná State Energy Company (COPEL, Companhia Paranaense de Energia) and Wobben–Enercon.

3.6. Port Mucuripe Wind Station

Set up in 1996, in the city of Fortaleza, this station was composed by 4300 kW Tacke Windtecnhik turbines, with 33-m diameter rotors and a 40-m high tower, amounting to a total installed capacity of 1.2 MW. The project was conceived and carried out by the Ceará State Energy Company (COELCE, Companhia Energética do Estado do Ceará) and the São Francisco Hydroelectric Company (CHESF, Companhia Hidroelétrica do São Francisco) in association and with financial support from the German Government and the State of Ceará. This station's average electricity generation was estimated at 3800 MWh/year. In 2002, this park's turbines went through a re-powering process, with the old turbines being replaced by 4E-40/600 kW Wobben Windpower aerogenerators, doubling therefore, the park's installed power.

3.7. Vila Joanes' wind–diesel–solar hybrid system—State of Pará

The system set up at Vila Joanes, Salvaterra district—Marajó Island, counts with 410 kW wind turbines, amounting to 40 kW of wind generated installed power, generating 800 kWh/year. This system also counts with 10.2 kWp of photovoltaic solar energy. The implementation of this park had direct support from the United States Department of Energy through the donation of the Bergey Wind Power turbines.

4. Legal boundary

The current electric energy market's flexible environment in the country and paradoxically the tightening of a supply crisis, have served as a conductor to the investor's interest raise in promoting actions that make the utilization of the

elevated Brazilian wind potential possible. This, coupled with the environmental pleas around the world, led the Brazilian Government to shape an institutional guideline that encourages the use of renewable technologies. Even though wind energy has been gaining ground among the cast of renewable resources with plausible utilization in Brazil, much of institutional demand is still to be defined, a number of restrictions and incentives are inserted into the legislation, causing impreciseness that has led investors to demand a firm and lasting regulation.

The real possibilities of establishing wind utilization with commercial purposes in the Brazilian private sector are legally upheld by Law number 9.074/1995, regulated by Edict number 2.003 of 1996 that deals with the rules for concession deferments and grants [8,9]. The quoted law creates the figure of an independent energy producer, defined as the enterprise or companies united in consortiums that receive concessions or authorization from the conceding authority, to produce totally or partially commercially designated electric energy at their own risk.

4.1. Fuel Consumption Bill—CCC (Conta de Consumo de Combustível)

Law number 5.99 of 1973, in its first edition, created the Fuel Consumption Bill (CCC, Conta de Consumo de Combustível), looking to subsidize electric energy generation from fossil fuels. The improvement of this law in 1993 disciplined the acquisition costs allotment of these fuels among all concessionaries and licensees in the country, in order to guarantee the financial resources for electric energy supply to consumers from isolated places of the generation and distribution network system. However, the promoted renovation of the electric sector, presenting the preferences of a competitive market, the international environmental pressures directed to adopting sustainable electric energy generation means and the imperative need to promote the appropriation of benefits resulting from the use of electric energy by every Brazilian citizen, culminated in inducing the creation of incentives to a wider penetration of forms of renewable generation. As a reflection of these new approaches, Law number 9.648 of 1998 extends the benefits of the CCC to all electric energy generation undertakings made from renewable sources aiming to substitute thermoelectric generation derived from fossil fuels in isolated systems. The end of the CCC's allotment is scheduled for the year 2013, thus leaving the institutional obligation of regulating and inspecting the submitted projects to the CCC's appeal [10] up to ANEEL.

4.2. Normative value—VN (valor normativo)

ANEEL, as a way to limit the passing of the price of electric energy bought by distributors on to final consumer rates, published Resolution number 233 of 1999 creating the Normative Value (VN, valor normativo), oriented at being a device favourable to the use of renewable energy sources of higher production costs, allowing for greater passing of generation costs onto the rates as a way to allow for the competitive establishment of these sources [11].

4.3. Emergency Wind Energy Program—PROEÓLICA (Programa Emergencial de Energia Eólica)

The House of Electric Energy Crisis Administration's (GCE, Câmara de Gestão da Crise de Energia Elétrica[1]) Resolution number 24 of 2001, created the Emergency Wind Energy Program—PROEÓLICA, aiming to promote the utilization of this source of energy as an economic, social and environmental alternative of energy development through actions that could, until December 2003, implement 1050 MW, 50 times the amount of production potential currently set up in the country, of electric energy generation possible from this source. The program foresaw incentives that assured the purchase for 15 years, by ELETROBRAS, of the energy produced by Wind Plants that became operational until December of 2003.

The value of the energy bought generated by PROEOLICA would be equivalent to the value of the rates passed on, relative to the Normative Value of the wind source established according to the regulations of ANEEL. The costs related to the volume of energy bought by ELETROBRÁS would be obligatorily passed on to distribution concessionaries of the network system proportionally to last year's market accomplishments. PROELICA however, was not able to make the emergency entrance of new wind projects possible, but did favour the entrance of many international companies that work with promoting renewable sources, thus generating the need of a long term legislative structure that accomplishes the development of the renewable energy market in Brazil [12].

4.4. Incentive Program to Alternative Electric Sources—PROINFA (Programa de Incentivo ás Fontes Alternativas Elétrica) and Energy Development Bill—CDE (Conta de Desenvolvimento Energético)

Law number 10.438 of 2002 created the incentive program to alternative electric sources—PROINFA (Programa de Incentivo ás Fontes Alternativas Elétrica) and the Energy Development Bill—CDE (Conta de Desenvolvimento Energético), with an aim of promoting the participation increase of electric energy produced by independent autonomous producers—PIA[2] (Produtores Independentes Autônomos) enterprises, conceived based on wind sources, small hydroelectric stations (PCH's, Pequenas Centrais Hidroelétricas) and biomass. Today, PROINFA is the legal reference to all government actions towards the development of renewable sources of energy in Brazil. In its first stage, the law foresees the implementation, until the year 2006, of 3300 MW evenly distributed among the sources [13].

[1] The House of Electric Energy Crisis Administration (GCE, Câmara de Gestão da Crise de Energia Elétrica)—created by the Federal Government in May 2001, aimed to propose and implement emergency measures before the critical hydrological situation, looking to make the demand and supply of electric energy compatible, thus avoiding unforeseen and untimely electric energy supply interruptions.

[2] Independent autonomous producers—PIA (Produtor Independente Autônomo) is that whose society is not controlled by or connected with an electric energy generation, transmission or distribution concessionary, nor its controllers or another society controlled or connected with the common controller.

In September of 2003, the temporary measure 127/03, by then already in president Luiz Inácio Lula da Silva's administration, promotes changes in PROINFA, changing the purchase guarantee of the energy generated in the program's ambit from 15 to 20 years, through contracts closed with ELETROBRAS until the end of April of 2004, for installations that become operational until December of 2006. The above mentioned contracts must be previously closed with the independent autonomous producers.

The temporary measure number 127/03 kept the right of direct participation of generation equipment manufactures, controlled, connected or controlling in PIA's constitution. However, it elevated the nationalization rate percentage of the equipments used in PROINFA's enterprises—previously determined as at least 50%—to a value of 75% [14].

The implementation of the initial 3300 MW must be evenly distributed in terms of installed capacity per each of the sources participating in the program and the energy acquired will be done by the corresponding economic value to each source's specific technology—VETEF[3] (Valor Econômico Correspondente à Tecnologia Específica de Cada Fonte). Law 10.436 determined that the corresponding economic values to wind source's specific technology, PCH's and biomass would initially have a minimum of 80% of the average national rate of supply to the final consumer[4] (Tarifa Média Nacional de Fornecimento ao Consumidor Final). While the temporary measure 127/03 changed this minimum to values of 50%, 70% and 90% of the mentioned rate for energy produced from biomass, PCH's and wind energy, respectively.

The amount paid for the electric energy acquired by ELETROBRAS, in PROINFA's ambit, will be shared among all final consumer classes, except the consumers of the residential subclass of low income—defined as consumers with a monthly consumption equal to or lower than 80 kWh/month—obeyed by the National Network System[5] (Sistema Interligado Nacional), proportionally to the individual consumption. After the installation planning of the first 3300 MW is due, PROINFA determines a second stage where the renewable sources shall be responsible, in 20 years, for 10% of all electric energy generation in Brazil.

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[3] Corresponding economic value to each source's specific technology (Valor Econômico Correspondente à Tecnologia Especifica de Cada Fonte): "electric energy sale value that at a certain time and for a certain efficiency level, makes it economically possible for a medium sized project using the referred source".

[4] Average national rate of supply to the final consumer (Tarifa Média Nacional de Fornecimento ao Consumidor Final): "quotient between the income from supply to electric system final consumers connected in the past 12 to the calculation and the respective consumption shown in R$/MWh.

[5] The Brazilian electric energy generation system has an installed capacity of 72,843 MW (December de 2002). It is predominantly hydro, with hydroelectric plants responsible for approximately 88% of the total installed power, the thermoelectric plants account for 9.3% and nuclear energy for 2.76%. The national network system (SNI, Sistema Interligado Nacional) comprises 96.6% of the electricity production capacity in the country, composed of generating units located in the South, Southeast, Midwest, Northeast and part of the North region. The other 3.4% of electric production capacity left unregarded by the SIN is found concentrated in small isolated systems, mostly in the Amazon region.

In this stage, the temporary measure 127/03 also raised the duration of the contracts to be signed with ELETROBRAS (initially, the Law 10.436 established a duration of 15 years) to 20 years. The price will be determined by the economic value corresponding to the competitive energy generation[6] (Valor Econômico Correspondente à Geração de Energia Competitiva). Each producer's annual amount of electric energy acquired will be programmed so that the referred sources supply the minimum 15% electric energy annual increment demanded by the national consumer market.

The acquisition of energy finalized by PROINFA, in this stage, will generate a complementary credit, defined as the result of the value difference between the corresponding economic value to each source's specific technology and the value received by ELETROBRAS, to be given to the energy producer, originated from the Energy Development Bill—(CDE, Conta de Desenvolvimento Energético).

ELETROBRAS might initially be authorized, by the executive power, to buy energy produced from independent producers not characterized as autonomous, as long as the volume of such contracts do not exceed 25% of the annual programme and that there is no offer neglecting from an independent autonomous producer. Temporary measure 127/03 established that, for wind enterprises only, the contracts signed in the first stage of PROINFA, must be evenly distributed among independent autonomous and non-autonomous producers.

The new institutional arrangement proposition of the electric sector presented by the Federal Government on December 11th 2003 brings new modifications to PROINFA, establishing that on the second stage of the programme "*the amount of renewable energy bought will be defined by the MME, taking into consideration the impact of hiring alternative sources forming the Regulated Hiring Environment (ACR, Ambiente de Contratação Regulado) supply rate, can not exceed 0.5% of this rate in any year, when compared to the growth based exclusively on conventional sources. Furthermore, the accumulated rate increases can not go over 5%*" [15].

By the new proposition, after the first stage of the PROINFA "the alternative sources shall compete among themselves for their share of the market. This way, there will be no need to establish any type of economic value definition for alternative sources to be passed on to the rate" [15].

From January 2005, the new model determines that "*only companies that can prove a 60% degree of services and equipment nationalization in each generation undertaking will be able to take part in the bidding process, meanwhile from 2007 onwards, this percentage shall go up to 90%*" [15].

4.5. Energy Development Bill—(CDE, Conta de Desenvolvimento Energético)

The creation of the Energy Development Bill—(CDE, Conta de Desenvolvimento Energético) aims at the energy development of the Brazilian States and the

[6] Economic value corresponding to the competitive energy generation (Valor Econômico Correspondente à Geração de Energia Competitiva): "average moderated cost of generation of new hydraulic utilization with a power of over 30,000 kW and natural gas thermoelectric stations.

competitiveness of generated energy from wind sources, PCH's, biomass, natural gas and national mineral coal in areas attended by the national network system and the promotion of generalization of electric energy services in all areas of the country. The CDE will have a 25-year duration and their resources will come from annual payments to the use of public well being (Uso de Bem Público); payments of fines by the ANEEL and payments of annual quotes from all agents that sell electric energy to the final consumer.

Among the possible uses of the CDE's resources, paragraph II of article 13 determines that it can be made available for:

> II. Payment of the differential between the Corresponding Economic Value to Each Source's Specific Technology and the Economic Value Corresponding to the Competitive Energy Generation to the electric energy producing agent from wind, thermal natural gas, biomass and PCH's sources, whose enterprises start up from the date of this Law's publication, when the purchase and selling is done with a final consumer [13].

5. Barriers and opportunities for the development of wind energy

5.1. Complementary to the hydro regime

Simulations, carried out by the Paraná State Energy Company—(COPEL, Companhia Paranaense de Eletricidade) and the Hydroelectric Company of the São Francisco—(CHESF, Companhia Hidroelétrica do São Francisco), made to identify the implications of wind utilization in the regularization of São Francisco river's flow, in the Northeast region and in the hydro regimes of the South and Southeast region's rivers point out a significant seasonal stabilization of energy supply through the complementarities of the natural hydrological and wind regimes [16].

The results of these studies, reaffirmed by the evaluations on the use of wind energy and the hydrology impacts on São Francisco River's bay, carried out along with the elaboration of the State of Ceará's Wind Atlas (Atlas Eólico do Estado do Ceará) [4], credits another attractive point to future wind enterprises, since Brazil is predominantly hydraulic in its electric energy generation basis, there is a constant need for energy storage in the plants reservoirs. As the hydro availability varies seasonally, the periods of little precipitation (dry period) demand a reservoir administration strategy in order to guarantee the supply on the safety and quality levels established. Fig. 2 shows a comparison of natural flow of the São Francisco River's effluents with the monthly average of total anemometric stations installed in the State of Ceará.

Meanwhile Fig. 3 shows the results of simulations made for natural flows of all hydroelectric plants in the Southeast region and the anemometric data of the South region.

The proof of existence of a large seasonal complementarity between the hydraulic regimes of the main bays and the wind regime, as shown in Figs. 2 and 3 inputs

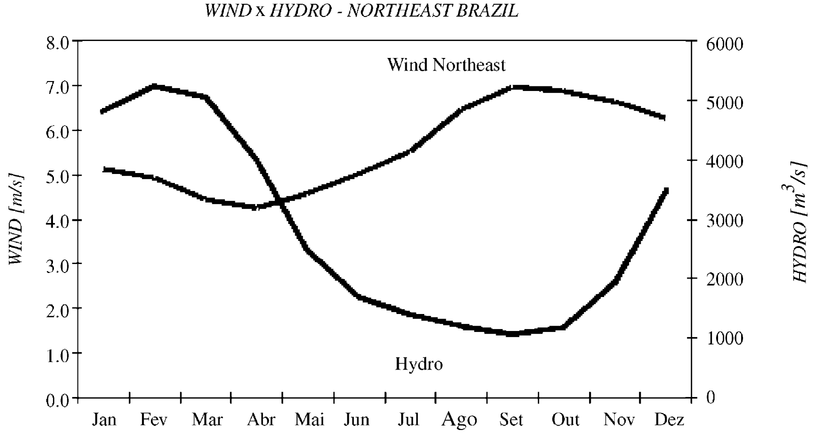

Fig. 2. Comparison of natural flow of São Francisco River whit the wind regime in the Northeast [4].

significant benefits into the national network system, indicating that it may be possible to add larger volumes of energy to the system exactly on the dry periods.

5.2. Infra-structure

The necessary infra-structure for the implementation of the wind parks presents itself as a problem to be overcome, as the parks with large scale turbines, with machines from 1 to 1.5 MW, require some land alteration, construction of roadways and the need for heavy forklifts. There are few forklifts of this type available in Brazil. The lifetime estimates for wind parks take the European experience into consideration. However, it will be imperative to follow the behaviour of utilizations located on the Northeaster's coastline, due to wind conditions, salinity and the

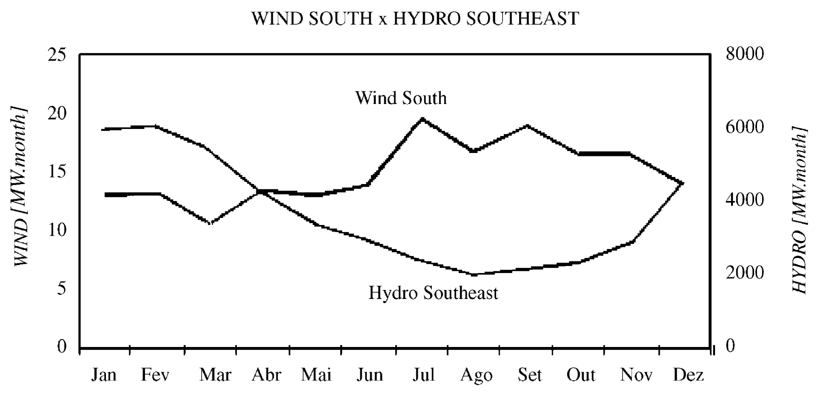

Fig. 3. Comparison of natural flow of all hydroelectric plants in southeast whit the wind regime in the South Region State [4].

occupation of dune areas, since the conditions found in these enterprises are very distinct from the ones in Europe.

5.3. Costs

The costs of wind utilization vary according to the aerogenerator power, height of the tower, rotor size, wind conditions, number of turbines, infra-structure and the price of the land, among others. Data show that, "in the 1990s, the cost for manufacturing wind turbines declined by about 20% every time the number of manufactured wind turbines doubled on average" [17]. The initial investments in wind utilization are in the US$ 1000/kW of installed power range [18,19].

The costs of wind energy investments have substantially decreased these past two decades and the tendency is for it to keep dropping for the next years. While the costs of energy show an even greater decrease, this tendency is credited to efficiency gains with the modern turbines, the availability of utilization, a turbine cost reduction and lower expenses with operation and maintenance.

The cost of wind utilization also tends to drop as the turbine size increases. Using a 600 kW machine in place of a 150 kW one, the costs are roughly tripled instead of quadrupling. The reason for this resides in the fact that there are scaled economies, once the hired labour quantity is not significantly altered, as well as the electronic equipment requirements, safety equipments and infra-structure expenses [19].

Setup costs include foundation building, normally done in armed concrete, roadways construction for the transportation of the turbine and sections of the tower, a transformer (to convert the tension generated to the network level), safety and telecommunication systems. Such costs vary according to region, as roadway construction costs depend on the region's relief and type of soil, cost of transportation and other related factors. There is scaled economy however, since it is cheaper to connect various turbines in the same area. On the other hand, the utilization is limited by the amount of electric energy that the local network supports.

The modern aerogenerators are projected to work for 120,000 h throughout its lifetime, which is estimated at 25 years. The wind utilization maintenance costs are very low at the beginning of the park's operation and rise as the turbine ages. In reality, an aerogenerator's lifetime depends as much on the turbine's quality as on the climate conditions of the area utilized.

The experiences in countries with a larger wind utilization show that for new machines, the maintenance costs are between 1.5% and 2% per year of the investments made in the park, or the equivalent to US$ 0.01/kWh [19].

Aiming to countersign the methodology and parameters utilized for the calculation of the alternative sources reference values, the Ministry of Mines and Energy promoted a public consultation in which it defined the VETEF for the sources contemplated in the PROINFA, for the values shown in Table 1. The calculations of these values used the deducted cash flow (Fluxo de Caixa Descontado) method as a basis adopting a minimal annual attractiveness rate of 14.89%.

Table 1
Economic values by source

Source	Specificity	VETEF—PROINFA first stage U$/MWh[a]	
		Area I	Area II
Biomass	Biogas	55.43	56.70
	Rice sector	30.05	37.55
	Wood sector	38.68	40.61
	Sugar–alcohol sector	39.87	29.86
Wind	Load factor $\leq$ 34%	73.93	77.22
	Load factor $\geq$ 44%	60.48	63.90
PCH		38.24	41.69

Area I comprehends the North and Northeast regions, while area II comprehends the rest of the country.
[a] The values presented were converted from the Brazilian currency (Real) at an exchange rate of 1 U$ = 3 R$.

Microeconomic analysis of wind utilization in Brazil reveals that the costs of wind energy generation are higher than those practiced by conventional forms of energy generation (hydraulic and thermal). Part of renewable source's higher expenses can be credited to the fact that environmental costs and externalizations generated by the conventional forms of energy production are not compensated by the producers, distributors and electricity consumers, but rather shared by national collectiveness.

As the externalizations generated by conventional energy sources start to compose their generation costs and an industrial wind park is structured in the country, this electro-wind alternative will also become feasible under perspective of the microeconomic analysis.

The investors that set up in the country demand, as a mean for their project's consolidation, a "fair" price for the MW generated and the purchase guarantee of this energy understanding it is necessary for the existence of a legal boundary that makes the development of renewable energies possible and guarantees the maintenance of utilization. Without this guarantee, it is stated that there will not be renewable energies in Brazil, and everything will become simply a momentary effort. In these terms, the consolidation of PROINFA meets, even if only partially, the requirements of investors, the government and civil society organized in search of consolidating an institutional scheme that really promotes, sustainedly, its consolidation.

5.4. Distribution and transmission systems impacts

The Brazilian park of electricity generation is supported by large blocks of generation, predominantly hydroelectric, away from the load centres and networked in a national system through long transmission lines that present load restrictions in various points. The decentralized utilizations are mainly located in isolated systems, and do not represent a considerable load flow volume of the national network system, as the total number of generation units and the volume generated

are still small when compared to the total load flow supplied to the system by large generation units. This means that, in Brazil, the degree of penetration by the distributed generation—(GP, Geração Distribuída) is small.

$$GP(\%) = [PG/(P + PG)] \cdot 100$$

where P, supplied load by external generation; PG, new load, supplied by local generation.

Decentralized electricity production, depending on the GP value, has the attractiveness of being able to act positively on the system in virtue of being closely located to the load centres, making a reduction in the transmission system's load profile available and favouring a network tension control and a reduction of losses present in transmission. Such benefits are more qualified when decentralized generation is made through thermoelectric units, as for these technologies the possible generation supply restrictions are not connected to the variability of the primary source that moves the turbine. This is the case of the wind turbines, which present a generation profile totally dependent on wind behaviour, speed and direction, in the exploration location. A raise in GP may introduce problems into the system related to the protection system, distribution network tension level control, automatic distribution network operation system flaws and reagents control [20].

In wind utilization, the wind profile variation causes a variation in generated power, registering momentary drops in power volume and even shutting down the generator unit due to lack of wind as well as due to the occurrence of wind speeds near to cut-out values.

The participation increase of the distributed energy elevated the difficulties of establishing pre-dispatch and dispatch of conventional plants due to power fluctuations generated in the distributed generation units. For the generation of electricity from aerogenerators this difficulty increases, since the future dispatch is an exclusive function of the wind existence at speeds and directions compatible with the installed aerogenerator's profile, making the existence of a reserve generation potential capable of supplying the power eventually not supplied by the wind generation units imperative.

The variability of the wind also results in more difficulties in the tension profile control of the system near to the generation unit imputing dynamic performance and tension quality drops, derived from power variations made available by the aerogenerator [20].

Generally, the impacts caused by larger wind energy penetration in the basis of the Brazilian electric generation will be closely related to the characteristics of the network in the connection area as well as the proximity of the load centres. If we take the installed power volume expected to become operational in Brazil as a basis, we can see that in the Northeast region these values add up to 4.56 GW, accounting for 75.5% of the load projected for the region (6041 MWaverage), making the execution of studies that point the wind park's behaviour as for four basic objectives of generation units imperative: generated energy quality and control, system balancing maintenance, tension control and short current supply. Therefore, the knowledge of regional distribution and transmission system impacts

reigns, as well as their national network system effects. Among the studies proposed by field specialists we can name:

- Ideal wind generation GP value determination;
- Relieves or reinforcements necessary in the transmission, sub-transmission and distribution system in areas around wind parks;
- Studies in permanent regimes and in dynamic regimes covering the shutting down of aerogenerators, the occurrence of short circuits and total energy generated variations.

5.5. The environmental variable

In general, the wind utilizations for electric energy generation do not pollute during its operation and result in a fossil fuel use reduction in developed countries, which avoids the emission of greenhouse effect intensifying gases. Opposed to what happens with conventional energy sources, the wind energy production does not implicate any changes to the phreatic sheet by consumption, contamination, residue generation or launches, as well as any large earth movement or prevention of its use. Modern wind parks operational around the world allow for the use of 99% of the occupied area for agricultural and other purposes [21].

In concerns to CO_2 emissions, Brazil has rates significantly lower than the world average of carbon per capita derived from the electric energy industry. The fact is justified by the strong hydroelectric presence in its basis. However, the Brazilian electric sector's expansion planning, derived from the competitive model in execution stage, points to an increase of thermoelectricity, based on natural gas, participation. This new orientation will necessarily lead to an emission increase associated to the Brazilian electric sector, independently of the technology and fuels employed. With this orientation the wind energy adoption shows itself as an alternative to cut down CO_2 emissions, if considered its use as a replacement for thermoelectric technologies. Table 2 shows a comparison of emissions as a result of different electricity production technologies shown in the renewable energy resources: opportunities and constraints 1992–2020 report [22].

Table 2 allows us to check that, among the technologies that have emissions lower than the ones registered by the electro-wind technology (geothermal, photovoltaics, large hydro and solar thermal), only the large hydro is structurally presented in a competitive way.

Studies carried out in Europe show that the amount of time needed for the recovery of the energy used in all the setup process of a wind park, from the start of its operation, is around 3–5 months. While the CO_2 emissions, derived, not from its operation, which is emission free, but from accounted emissions in equipment production, transportation and setup, are calculated between 7 and 10 g CO_2/kWh [21,23].

Considering the fact that there is not a commercially structured wind industry in Brazil, the importation of almost all of the equipment to be employed in future wind parks becomes necessary at a first stage. In this context, the return time of

Table 2
CO_2 emissions by electric generation technology [22]

CO_2 emission—ton/GWh				
Technology	Extraction	Construction	Operation	Total
Coal-fired	1	1	962	964
Oil-fired	–	–	726	726
Gas-fired	–	–	484	484
Geothermal	<1	1	56	57
Small hydro	N/A	10	N/A	10
Nuclear	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood	−1509	3	1346	−160

energy used in the setup process of these parks and the accountability of their CO_2 emissions will have similar patterns to the ones in Europe. At a second stage, with the establishment of an industrial wind park, these rates will tend to drop, once the calculation of these factors are done according to the type of fuel and technology used for energy production and Europe possesses a fossil fuel dependent energy basis, as opposed to the Brazilian electric producer park which is predominantly hydro.

All corporative studies on environmental impact analysis of the various forms of electricity generation show that the wind kWh is by far the cleanest. Hence, the wind energy development may be an important component of an energy policy whose objectives are the guarantee of security in the country's supply and the preservation of the environment.

In this current scenario, the wind energy participation increase in the electric basis come with an environmental attractive related to the fact its utilization is one of the cheapest methods of CO_2 emission reduction in the electric energy production, thus avoiding emissions derived from future thermoelectric plants and contributes to the maintenance of the clean characteristics of its electric basis.

6. Wind utilization projects underway in Brazil

The recent actions conducted by the public and private sector aiming to make precise wind data available proved the existence of practically non-stop winds in the country's shore, thus indicating, the existence of a huge unexplored wind potential. The authorization requests for wind resources utilization feasibility studies already total 6568.50 MW, as shown in Table 3.

The space distribution evaluation of the wind projects in study in Brazil come about confirming the predominance of investor's interest in areas located on the North-eastern coast. The fact occurs due to the excellent characteristics of wind behaviour in this region—high average speeds with little variability and directions

Table 3
Wind parks authorized by ANEEL [24]

Region	State	Number of parks	Power (MW)
Northeast	Ceará	34	2270.35
	Rio Grande do Norte	22	2114.3
	Pernambuco	5	247.90
	Bahia	2	90.10
	Sergipe	1	29.70
	Piaui	2	123.70
	Northeast total	66	4876.05
Southeast	Rio de Janeiro	3	214.55
	Southeast total	3	214.55
South	Rio Grande do Sul	26	1369.3
	Santa Catarina	2	48.60
	South total	28	1417.9
North	Pará	1	60.00
	North total	1	60
Brazil	Brazil total	98	6568.5

predominantly showing little change, such characteristics make the establishment of a capacity factor way above the ones in the rest of the country and in Europe possible.

7. Conclusions

In the 1990s, a lot of renovations were promoted in the Brazilian electric sector aiming at the implementation of a market model. In this process, distribution and generation companies were privatized, the independent producer figure was created and a new interpretation of the environmental implications of electric utilizations started to determine the decisions of the system expansion planning. This group of factors, along with the electric supply crisis that took place in 2001 has created conditions for an alternative sources participation increase in the Brazilian electric basis, especially for wind energy.

The wind energy participation increase must be planned out so that it is inserted into the Brazilian system's mix, having to also be worthwhile from a commercial point of view, as it is very complementary in terms of regional necessities. If the South of the country has a large hydro supply, the same does not happen in the Northeast, which in turn has a brutal wind energy supply, which is a wasted fuel, not utilized.

Without disturbing the Brazilian electro-producer system, from an economic and technical point of view, it is possible to implement at least 12,000 MW until the year 2010. Brazil lives today the discovery of wind energy with approximately 6 GW in feasibility study stage and the structuring of a legal boundary that shall guarantee the expansion of this source, in regulating stage.

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